Rec'd PCT/PTO SEP 18 2001

~~29 1. A crystal growth method for adding or crystallizing nitrogen in a crystal, comprising~~

~~a step of supplying aluminum and ammonium (NH_3) to a surface of the crystal,~~

~~wherein addition or crystallization of the nitrogen from the ammonium which is supplied to the surface of the crystal into the surface of the crystal is accelerated by the aluminum supplied to the surface of the crystal.~~

Sub B1

30 ~~2~~. A crystal growth method according to claim 1, wherein decomposition of ammonium and adsorption of nitrogen on a crystal surface is accelerated by aluminum.

A1

31 ~~3~~. A crystal growth method according to claim 1, wherein the aluminum exists at least in an outermost surface of a growing layer.

32 ~~4~~. A crystal growth method according to claim 1, wherein an amount of nitrogen added to a crystal, a nitrogen composition, an amount of nitrogen adsorbed on a crystal surface and an amount of an element in the crystal surface

which is substituted with a nitrogen atom are controlled based on an amount or composition ratio of added aluminum.

33 ~~5~~. A crystal growth method according to claim 1, wherein aluminum is added to or crystallized in a restricted region, whereby only in the restricted region, nitrogen is added or crystallized, a nitrogen atom is adsorbed, or an element in a crystal surface is substituted with a nitrogen atom.

Al cont

34 ~~6~~. A crystal growth method according to claim 1, wherein a method selected from among a molecular beam epitaxial (MBE) growth method, a metal organic molecular beam epitaxial (MO-MBE) growth method, a gas source molecular beam epitaxial (GS-MBE) growth method, and a chemical beam epitaxial (CBE) growth method is used.

35 ~~7~~. A crystal growth method according to claim 1, wherein crystal growth of a III-V compound semiconductor including, as V group components, nitrogen and a V group element other than nitrogen is performed.

36 ~~8~~. A crystal growth method according to claim 35 ~~7~~, wherein at least one of arsenic (As), phosphorus (P), and

antimony (Sb) is selected as the V group element other than nitrogen.

37 ~~9~~. A crystal growth method according to claim 35 ~~7~~, wherein a substrate temperature is in a range from 450°C to 640°C.

A1 cont

38 ~~10~~. A crystal growth method according to claim 1, wherein a surface of single crystal substrate is a crystal surface slanted from a (100) surface in a [011] direction (A direction) or a crystal face which is equivalent in a crystallographic sense to the slanted crystal surface.

39 ~~11~~. A crystal growth method according to claim 38 ~~10~~, wherein the slant angle is within a range equal to 2° or more and equal to 25° or less.

40 ~~12~~. A crystal growth method according to claim 1, wherein one or more pairs of semiconductor layer A and semiconductor layer B are superposed, the semiconductor layer A including at least aluminum and nitrogen in its composition but not including indium in its composition, and the semiconductor layer B including at least indium in its composition but not including nitrogen in its composition.

41 ~~13~~. A crystal growth method according to claim ~~12~~ 40, wherein the thickness of each of the semiconductor layers A and B is one molecular layer or more, and ten molecular layers or less.

42 ~~14~~. A crystal growth method according to claim 1, wherein crystal growth is performed by applying a source material to a substrate in a crystal growth room which is evacuated of air, and a mean free path of a molecule of each source material is longer than a distance between the substrate and a source of the source material.

43 ~~15~~. A crystal growth method according to claim 1, wherein ammonium in the form of gas is used as a nitrogen source material, and a source material of another element is obtained by evaporating a solid of a single element.

44 ~~16~~. A crystal growth method according to claim 1, wherein ammonium in an undecomposed state is supplied as a nitrogen source material and decomposed on a surface of the substrate.

45 ~~17~~. A crystal growth method according to claim 1, wherein crystal growth is performed over an underlying (substrate) crystal which does not include nitrogen as a principal element.

46 ~~18~~. A crystal growth method according to claim 45 ~~17~~, wherein the underlying (substrate) crystal is selected from GaAs, InP, GaP, GaSb, and Si.

A1 cont

47 ~~19~~. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim 1.

48 ~~20~~. A semiconductor device according to claim 47 ~~19~~, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

49 ~~21~~. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim 38 ~~10~~.

50 ~~22~~. A semiconductor device according to claim 49 ~~21~~, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

51 ~~23~~. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim 40 ~~12~~.

52 ~~24~~. A semiconductor device according to claim 51 ~~23~~, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

A1 cont

53 ~~25~~. ~~A system which uses the semiconductor device of claim 47 19.~~

Sub B3

54 ~~26~~. ~~A system which uses the semiconductor device of claim 49 21.~~

55 ~~27~~. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim 42 ~~14~~.

56 ~~28~~. A semiconductor device according to claim 55 ~~27~~, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

57 ~~29~~. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim 43 ~~15~~.

58 ~~30~~. A semiconductor device according to claim 57 ~~29~~, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

A1 cont

59 ~~31~~. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim 44 ~~16~~.

60 ~~32~~. A semiconductor device according to claim 59 ~~31~~, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

61 ~~33~~. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim 45 ~~17~~.

62 ~~34~~. A semiconductor device according to claim 61 ~~33~~, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

63 ~~35~~. A crystal growth method for adsorbing a nitrogen atom on a surface of a crystal, the crystal including aluminum in the surface thereof, comprising steps of:

growing the crystal including the aluminum on the surface; and

supplying ammonium (NH_3) to the surface of the crystal including the aluminum in the surface thereof,

Al cont

wherein adsorption of the nitrogen atom generated by decomposition of the ammonium supplied to the surface of the crystal is accelerated by the aluminum included in the surface of the crystal.

64 ~~36~~. A crystal growth method according to claim 63 ~~35~~, wherein decomposition of ammonium and adsorption of nitrogen on a crystal surface is accelerated by aluminum.

65 ~~37~~. A crystal growth method according to claim 63 ~~35~~, wherein the aluminum exists at least in an outermost surface of a growing layer.

66 ~~38~~. A crystal growth method according to claim 63 ~~35~~, wherein an amount of nitrogen added to a crystal, a nitrogen composition, an amount of nitrogen adsorbed on a crystal surface and an amount of an element in the crystal

surface which is substituted with nitrogen are controlled based on an amount or composition ratio of added aluminum.

~~39~~ 67. A crystal growth method according to claim ~~35~~ 63, wherein aluminum is added to or crystallized in a restricted region, whereby only in the restricted region, nitrogen is added or crystallized, a nitrogen atom is adsorbed, or an element in a crystal surface is substituted with a nitrogen atom.

A cont

~~40~~ 68. A crystal growth method according to claim ~~35~~ 63, wherein a method selected from among a molecular beam epitaxial (MBE) growth method, a metal organic molecular beam epitaxial (MO-MBE) growth method, a gas source molecular beam epitaxial (GS-MBE) growth method, and a chemical beam epitaxial (CBE) growth method is used.

~~41~~ 69. A crystal growth method according to claim ~~35~~ 63, wherein crystal growth of a III-V compound semiconductor including, as V group components, nitrogen and a V group element other than nitrogen is performed.

~~42~~ 70. A crystal growth method according to claim ~~41~~ 69, wherein at least one of arsenic (As), phosphorus (P), and

antimony (Sb) is selected as the V group element other than nitrogen.

71 ~~43~~. A crystal growth method according to claim 69 ~~41~~, wherein a substrate temperature is in a range from 450°C to 640°C.

A1 cont

72 ~~44~~. A crystal growth method according to claim 63 ~~35~~, comprising a series of steps including at least steps of:

supplying a III group source material including aluminum of less than one atomic layer;

subsequently, supplying ammonium so as to adsorb nitrogen atoms of less than one atomic layer; and

supplying a source material of a V group element other than nitrogen,

wherein the series of steps are repeated one time or more.

73 ~~45~~. A crystal growth method according to claim 72 ~~44~~, wherein in the step of supplying ammonium so as to adsorb nitrogen of less than one atomic layer, the source material of the V group element other than nitrogen is not supplied at the same time.

74 ~~46~~. A crystal growth method according to claim 72 ~~44~~, wherein crystal growth is performed over a single crystal substrate in which a {100} surface is a principal plane.

75 ~~47~~. A crystal growth method according to claim 74 ~~46~~, wherein a surface of the single crystal substrate is a crystal surface slanted from a (100) surface in a [011] direction (A direction) or a crystal face which is equivalent in a crystallographic sense to the slanted crystal surface.

A1 cont

76 ~~48~~. A crystal growth method according to claim 75 ~~47~~, wherein the slant angle is within a range equal to 2° or more and equal to 25° or less.

77 ~~49~~. A crystal growth method according to claim 63 ~~35~~, wherein one or more pairs of semiconductor layer A and semiconductor layer B are superposed, the semiconductor layer A including at least aluminum and nitrogen in its composition but not including indium in its composition, and the semiconductor layer B including at least indium in its composition but not including nitrogen in its composition.

Sub B4

78 ~~50~~. A crystal growth method according to claim 77 ~~49~~, wherein the thickness of each of the semiconductor layers A and B is one molecular layer or more, and ten molecular layers or less.

A1 cont

79 ~~51~~. A crystal growth method according to claim 63 ~~35~~, wherein crystal growth is performed by applying a source material to a substrate in a crystal growth room which is evacuated of air, and a mean free path of a molecule of each source material is longer than a distance between the substrate and a source of the source material.

80 ~~52~~. A crystal growth method according to claim 63 ~~35~~, wherein ammonium in the form of gas is used as a nitrogen source material, and a source material of another element is obtained by evaporating a solid of a single element.

81 ~~53~~. A crystal growth method according to claim 63 ~~35~~, wherein ammonium in an undecomposed state is supplied as a nitrogen source material and decomposed on a surface of the substrate.

82 ~~54~~. A crystal growth method according to claim 63 ~~35~~, wherein crystal growth is performed over an underlying

(substrate) crystal which does not include nitrogen as a principal element.

~~55~~ 83. A crystal growth method according to claim ~~54~~ 82, wherein the underlying (substrate) crystal is selected from GaAs, InP, GaP, GaSb, and Si.

At cont

~~56~~ 84. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim ~~35~~ 63.

~~57~~ 85. A semiconductor device according to claim ~~56~~ 84, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

~~58~~ 86. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim ~~47~~ 75.

~~59~~ 87. A semiconductor device according to claim ~~58~~ 86, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

~~60~~ 88. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim ~~49~~ 77.

~~61~~ 89. A semiconductor device according to claim ~~60~~ 88, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

A1 cont

~~62~~ 90. ~~A system which uses the semiconductor device of claim 56~~ 84.

Sub B5

~~63~~ 91. ~~A system which uses the semiconductor device of claim 60~~ 88.

~~64~~ 92. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim ~~51~~ 79.

~~65~~ 93. A semiconductor device according to claim ~~64~~ 92, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

~~66~~ 94. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim ~~52~~ 80.

~~67~~ 95. A semiconductor device according to claim ~~66~~ 94, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

A1 cont

~~68~~ 96. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim ~~53~~ 81.

~~69~~ 97. A semiconductor device according to claim ~~68~~ 96, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

~~70~~ 98. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim ~~54~~ 82.

~~71~~ 99. A semiconductor device according to claim ~~70~~ 98, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

Sub Ble 1

~~72~~ 100. A crystal growth method for substituting a portion of elements included in a crystal surface with nitrogen

atoms, the surface of the crystal further including aluminum, comprising steps of:

growing the crystal; and

supplying ammonium (NH_3) to the surface of the crystal,

wherein substitution of the portion of the elements with the nitrogen atom from the ammonium supplied to the surface of the crystal is accelerated by the aluminum included in the surface of the crystal.

Sub B4 Cl

A1 cont concl

101 ~~73~~. A crystal growth method according to claim 100 ~~72~~, wherein decomposition of ammonium and adsorption of nitrogen on a crystal surface is accelerated by aluminum.

102 ~~74~~. A crystal growth method according to claim 100 ~~72~~, wherein the aluminum exists at least in an outermost surface of a growing layer.

103 ~~75~~. A crystal growth method according to claim 100 ~~72~~, wherein an amount of nitrogen added to a crystal, a nitrogen composition, an amount of nitrogen adsorbed on a crystal surface and an amount of an element in the crystal surface which is substituted with nitrogen are controlled based on an amount or composition ratio of added aluminum.

104 ~~76~~. A crystal growth method according to claim 100 ~~72~~, wherein aluminum is added to or crystallized in a restricted region, whereby only in the restricted region, nitrogen is added or crystallized, a nitrogen atom is adsorbed, or an element in a crystal surface is substituted with a nitrogen atom.

A1 cont

105 ~~77~~. A crystal growth method according to claim 100 ~~72~~, wherein a method selected from among a molecular beam epitaxial (MBE) growth method, a metal organic molecular beam epitaxial (MO-MBE) growth method, a gas source molecular beam epitaxial (GS-MBE) growth method, and a chemical beam epitaxial (CBE) growth method is used.

106 ~~78~~. A crystal growth method according to claim 100 ~~72~~, wherein crystal growth of a III-V compound semiconductor including, as V group components, nitrogen and a V group element other than nitrogen is performed.

107 ~~79~~. A crystal growth method according to claim 106 ~~78~~, wherein at least one of arsenic (As), phosphorus (P), and antimony (Sb) is selected as the V group element other than nitrogen.

~~80~~ 108. A crystal growth method according to claim ~~78~~ 106, wherein a substrate temperature is in a range from 450°C to 640°C.

A1 cont

~~81~~ 109. A crystal growth method according to claim ~~72~~ 100, comprising a series of steps including at least steps of: forming a III-V compound crystal layer including at least one molecular layer of aluminum; and subsequently, supplying ammonium so as to substitute a portion of V group atoms in the III-V compound crystal layer with nitrogen atoms, wherein the series of steps are repeated one time or more.

~~82~~ 110. A crystal growth method according to claim ~~72~~ 100, comprising at least steps of:

crystal-forming a layered structure including at least a first semiconductor layer containing aluminum and a second semiconductor layer superposed thereon;

etching the layered structure while masking a portion of the layered structure such that the first semiconductor layer is exposed in a portion of an etched surface; and

supplying ammonium to the etched surface while

heating the layered structure such that at least a portion of a constituent element in the first semiconductor layer is substituted with nitrogen.

Sub B7 A1 cont

111 ~~83~~. A crystal growth method according to claim 110 ~~82~~, wherein the etched surface is a (n11)A surface (n=1, 2, 3,...).

112 ~~84~~. A crystal growth method according to claim 100 ~~72~~, wherein a surface of single crystal substrate is a crystal surface slanted from a (100) surface in a [011] direction (A direction) or a crystal face which is equivalent in a crystallographic sense to the slanted crystal surface.

113 ~~85~~. A crystal growth method according to claim 112 ~~84~~, wherein the slant angle is within a range equal to 2° or more and equal to 25° or less.

114 ~~86~~. A crystal growth method according to claim 100 ~~72~~, wherein one or more pairs of semiconductor layer A and semiconductor layer B are superposed, the semiconductor layer A including at least aluminum and nitrogen in its composition but not including indium in its composition, and the semiconductor layer B including at least indium

in its composition but not including nitrogen in its composition.

Sub B8

~~87~~ 115. ~~A crystal growth method according to claim~~ ~~86~~ 114~~, wherein the thickness of each of the semiconductor layers A and B is one molecular layer or more, and ten molecular layers or less.~~

A1 cont

~~88~~ 116. A crystal growth method according to claim ~~72~~ 100, wherein crystal growth is performed by applying a source material to a substrate in a crystal growth room which is evacuated of air, and a mean free path of a molecule of each source material is longer than a distance between the substrate and a source of the source material.

~~89~~ 117. A crystal growth method according to claim ~~72~~ 100, wherein ammonium in the form of gas is used as a nitrogen source material, and a source material of another element is obtained by evaporating a solid of a single element.

~~90~~ 118. A crystal growth method according to claim ~~72~~ 100, wherein ammonium in an undecomposed state is supplied as a nitrogen source material and decomposed on a surface of the substrate.

A1 cont

~~91~~ 119. A crystal growth method according to claim ~~72~~ 100, wherein crystal growth is performed over an underlying (substrate) crystal which does not include nitrogen as a principal element.

~~92~~ 120. A crystal growth method according to claim ~~91~~ 119, wherein the underlying (substrate) crystal is selected from GaAs, InP, GaP, GaSb, and Si.

~~93~~ 121. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim ~~72~~ 100.

~~94~~ 122. A semiconductor device according to claim ~~93~~ 121, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

~~95~~ 123. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim ~~84~~ 112.

~~96~~ 124. A semiconductor device according to claim ~~95~~ 123, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer

thereof.

125 ~~97~~. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim 114 ~~86~~.

A1 cont

126 ~~98~~. A semiconductor device according to claim 125 ~~97~~, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

127 ~~99~~. A method for forming a semiconductor microwire structure wherein:

the crystal growth method of claim 110 ~~82~~ is used when forming a semiconductor microstructure having a periodically-positioned wire pattern;

a diffraction grating is formed by the step of etching the layered structure while masking a portion of the layered structure such that the first semiconductor layer is exposed in a portion of an etched surface; and

a periodical wire structure is formed at a 1/2 of the pitch of the diffraction grating by the step of supplying ammonium to the etched surface while heating the layered structure such that at least a portion of a constituent element in the first semiconductor layer is

substituted with nitrogen.

A1 cont.

~~100~~ 128. A method for forming a semiconductor microwire structure according to claim ~~99~~ 127, wherein the wire structure is an absorptive diffraction grating section of a gain-coupled distributed feedback semiconductor laser having an absorptive diffraction grating, or a quantum wire.

~~101~~ 129. A method for forming a semiconductor microwire structure according to claim ~~99~~ 127, wherein ammonium in an undecomposed state is supplied as a nitrogen source material and decomposed on a surface of the substrate.

~~102~~ 130. A method for forming a semiconductor microwire structure according to claim ~~99~~ 127, wherein crystal growth is performed over an underlying (substrate) crystal which does not include nitrogen as a principal element.

~~103~~ 131. A method for forming a semiconductor microwire structure according to claim ~~102~~ 130, wherein the underlying (substrate) crystal is selected from GaAs, InP, GaP, GaSb, and Si.

~~104~~ 132. A system which uses the semiconductor device of claim ~~93~~ 121.

Sub B9

~~105~~ 133. A system which uses the semiconductor device of claim ~~95~~ 123.

A1 cont

~~106~~ 134. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim ~~88~~ 116.

~~107~~ 135. A semiconductor device according to claim ~~106~~ 134, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

~~108~~ 136. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim ~~89~~ 117.

~~109~~ 137. A semiconductor device according to claim ~~108~~ 136, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

~~110~~ 138. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim ~~90~~ 118.

139 ~~111~~. A semiconductor device according to claim 138 ~~110~~, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.

A1 end

140 ~~112~~. A semiconductor device comprising a semiconductor layer formed by the crystal growth method of claim 119 ~~91~~.

141 ~~113~~. A semiconductor device according to claim 140 ~~112~~, wherein the semiconductor device is a light emitting element, and the semiconductor layer forms a light emitting layer thereof.